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Evaluation the Impact of Flexible Joints and Deck on the Seismic Response of Bridges

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ABSTRACT

Bridges have undeniable importance at different parts of urban areas. In this study the influence of various forms of bridge decks, flexible joints and other elements of concrete bridges with diverse size have investigated, because of high rate of popularity of concrete bridges in construction project. Due to the significance of plastics in analyzing the seismic response of bridges, finite element model is chosen in this project. In the present study, two types of hinges, including fiber hinge and the force moment interactive hinge (PMM), have been selected to indicate the ductility of the columns in the lower and upper regions of the abutments and in the length of the plastic hinge. A huge decrease can be seen in dissipation of energy through pier, by interpreting the data of designed models and effect of dedicated earthquake force. Therefore, to reach better efficiency, it is suggested strengthening the seismic behavior of traditional bridges. To assess short bridges, roller model is not a reliable way to get accurate results, but in long bridges with the length of more than 95m, a simple model can be set to evaluate bridge response.

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1. Introduction

Bridges, as one of the most important man-made structures, play an essential role in everyday urban life [1]. Service bridges are especially important for helping people, especially in crisis and aid processes [2]. Heavy ground movement over the past decade in densely populated areas has dealt many blows to many bridges, especially those designed in accordance with older regulations, and their vulnerability must be taken into account in the interaction of soil and structure. Check the contract [3]. Therefore, the study of the vulnerability of highways and urban bridges is very important because an important artery in the highway transportation system seems necessary. Therefore, Seismic separation, a novel method designed as an accurate and profitable alternative to seismic design and optimization of highway bridges, has been developed. Using seismic separators on bridges increases ductility and reduces the seismic forces on the bridge structure. This will increase the seismic performance of bridges under severe earthquakes to provide emergency relief after an earthquake. Detachable supports on the bridge are mechanical devices whose function is to transmit the support reaction and lateral forces to the bridge deck [4].

Kelly JM [5] Recent years, many researchers have tried to find ways to prevent earthquakes, most of which have used seismic separators to dissipate energy.

Afghan [6] Contrary to popular belief, seismic separation tries to reduce demand instead of increasing capacity. By adding an insulating device between the superstructure and the piers, the seismic force on the bridge can be reduced. The separation device separates the superstructure movements from the docks and pedestals during an earthquake. Thus, the natural period of a structure extends to a higher value than the period of stimulation of the seismic. As a result, it reduces seismic forces near the elastic capacity of structural components to prevent ground motion due to indirect deformation. Mitoulis et al. (2013) [7] in this project, when confronted with the task of reinforcing a bridge, a designer has two options to consider and combine: a) increasing capacity or b) reducing structural measures. The reduction of bridge actions is mainly by using an external restraint system consisting of I-shaped steel piles driven into the back soil and a boulder that is the piles of piles of piles. The restraining system was originally designed and evaluated in an existing MSSS bridge system, whose rig plate is continuously constructed. Using non-linear dynamic history analysis and analysis of available time and rehabilitated bridge, the serviceability and seismic resistance of their responses were compared. The research found that the reinforcement scheme effectively increased earthquake resistance on the current bridge. Mitoulis et al. (2016) [8], this research proposes a unique isolator, which is a compressible inclusion of recycled tyre-derived aggregates put between the bridge abutment and the backfill, as a solution to the aforementioned difficulties. Laboratory measurements were used to determine the compressibility of common tyre-derived aggregates, and the compressible inclusion was built appropriately. After that, the compressible inclusion was applied to a standard integral frame abutment model, which was subjected to static and dynamic loads that represented in-service and seismic stresses, respectively. Based on backfill settlements, soil pressures, and abutment actions, the conventional and isolated abutments' responses were evaluated. The isolated abutment research revealed that successfully decoupling the abutment from the backfill soil leads in considerable reductions in backfill settlements and forces acting on the abutment. As a result of the suggested research, the length limitations of integral frame bridges subjected to seismic excitations can be extended. Amin et al. [9] in this paper, purpose of this research is numerical investigation of integrated bridge system in geochemically stabilized land with static loading. In this project, the seismic behavior of v-shaped bridges was analyzed by considering the effects of bags and plastic hinges, the effect of three different types of abutments and plastic joints and the modeling of other components related to six models of concrete bridges with different height and length. To investigate these effects, the results of ATC-40 [10] nonlinear static and nonlinear dynamic analysis were used. The results of the analyzes were calculated as the maximum base shear and displacement. In this study, two bridges with two different heights of 6 and 8 m were modeled with 5 and 6 spans. Simplified bridge deck models are used in the majority of the studies mentioned above. However, it is critical to accurately record the seismic distribution of deck forces over the width and height of the abutments and the plastic hinge backwall, as well as to examine these bridges more closely in order to determine their overall seismic susceptibility, Especially when the high frequency of hammering forces is taken into consideration. In this context, the study's major goals are to explore and compare the seismic performance of both isolated and conventional bridge systems. Furthermore, the seismic involvement of the traditional bridge's sacrifcial abutment was assessed in terms of energy dissipation by piers. A comparison of two case study bridges will be used to conduct the inquiry. For dynamic time history analysis, nonlinear 3D models are developed and employed. The total system's reaction, as well as the responses of individual components, are compared and the acceptability limits are evaluated.

2. Characteristics and modeling of the bridges studied

In this study, four types of bridge models were modeled at two different heights of 6 and 8 m with 5 and 6 spans. Modeling of various bridges components is used to analyze the nonlinearity of bridges, expected strength of materials and stress-strain relationship for confined and non-confined concrete as well as reinforcing bars to obtain capacity and investigate bridge behavior. The properties of the longitudinal and transverse bars are modeled according to the characteristics of the elastic and non-elastic behavior. The modeling of the various components of bridges, including base materials, decks, abutments, columns, columns head, is described below. In this study, all columns in the bridges have circular cross-sections and with a clamped connection are connected to the foundation and the flexibility of the foundations is ignored.

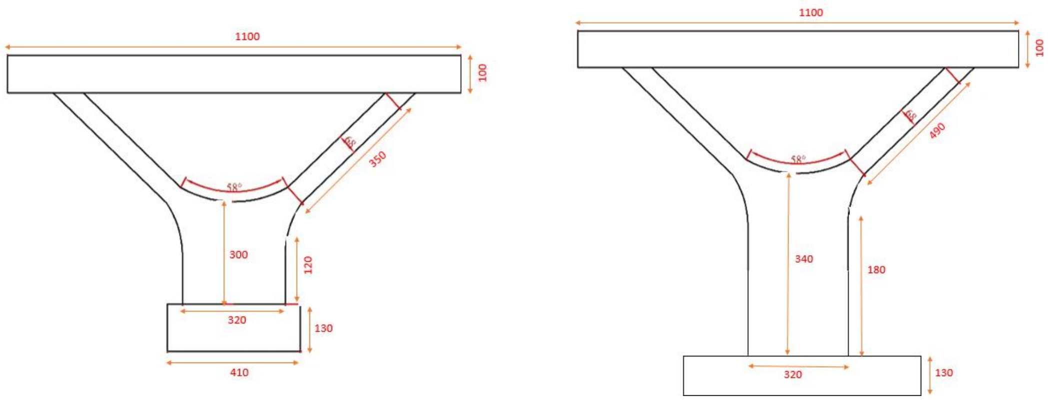


Fig. 1. Overview of the investigated bridge Columns Height 6, 8 meter.

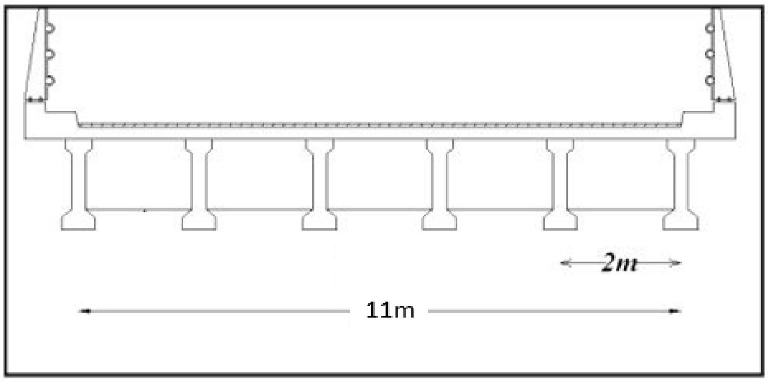


Fig. 2. Cross section of bridge decks.

Table 1
General specifications of the bridge.

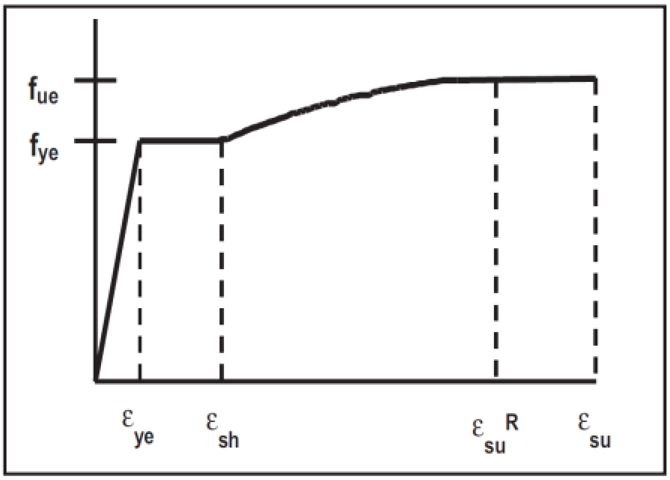
The number of spans in the upright direction	5 and 6 spans
Deck type	beam-slab
The width of the deck	11 meters
Slab thickness	14 cm
The number of the girder	6 and 7
The kind of girder	Concrete
Spacing of girders	19 and 15.83 meters
Dimensions of the life of the girders	1.2 * 0.22 meters
	0.2 * 0.5 meters
The dimensions of the girder's wings	0.15 * 0.55 meters
Height Column foundations	6 and 8 meters
Type of foundation	Deep (assumed restrained)
Type of abutment	Package and reinforced concrete
Connect the abutment to the deck	The assumed roller
Slabs rebar size	25

3. Specifications of concrete and steel materials

The california seismic design code CALTRANS [11] and Mander et al. [12], in this paper model is used to model the behavior of steel and concrete. The transverse bars at the base of the bridges increase the compressive strength and ultimate strain of the concrete by enclosing the cross-section core. Therefore, model Mander et al. (1988) [12] is used to determine the ductility capacity of concrete members using a nonlinear strain stress model for confined and non-confined concrete according to Figure 4a and presenting the actual concrete behavior based on the relation (1). In this respect, f'_{cc} is the compressive stress of the concrete and ε_{cc} is the strain corresponding to the maximum compressive stress of the confined concrete andf'_1 is the effective confining stress for the circular sections. Due to the average shear stress and E_c, E_{sec} respectively, the tensile modulus of concrete and the modulus corresponding to maximum compressive stress are respectively. Using them can be used to obtain specifications for non-enclosed concrete. In this respect, the effect of the coefficient of confinement K_e and its value for the circular cross-sections is 0.95. f_1 is the maximum effective lateral pressure.

$$f_c = \frac{xrf'_{cc}}{r-1+x}$$

$$x = \frac{\varepsilon_c}{\varepsilon_{cc}}, r = \frac{E_c}{E_c-E_{sec}}, f'_{cc} = f'_c\left(2.254\sqrt{1+\frac{7.94f'_l}{f'_c}} - \frac{2f'_l}{f'_c} - 1.254\right), f'_l = K_e f_l, f_l = \frac{2f_{yh}A_{sp}}{D'S} \qquad (1)$$



(B) The strain stress diagram of the rebars.

Fig. 3. Stress-strain diagram [11].

Because the yield limit is the transverse bars. The behavior of the bars (Figure 3) is modeled with a stress-strain relation with the initial elastic linear, steady, and stiffness behavior proportional to the stress-strain increase. The corresponding yield point according to the expected yield stress of the steel and the length of the steady yield region is a function of the steel strength and bar diameter.

4. Modeling

The linear elastic model of the abutment must include the actual value for the embankment response and the effective stiffness of the K_eff abutment. The hardness of embankment abutment is nonlinear and depends on embankment materials. The influence of impact and oscillating loads based on the results of research [13], the initial hardness of abutments under the influence of impact and oscillating loads Ki = 11.5 × 102 kg / m to adjust the initial hardness according to the ratio of the end wall to the height of the deck of the relationship (2) has been used.

$$K_{abt} = K_i \times W \times \left(\frac{h}{1.7}\right) \tag{2}$$

In this regard, w is the width of the end wall or deck for continuous and simple abutments. The hardness of the abutment t (Kabt) and the resulting end wall strength (Pbw) are used for longitudinal direction using CL = 2/3 wall impact coefficient and Cw = 4/3 wall participation coefficient to calculate the stiffness of the abutment in the transverse direction [13]. The length of the wing wall according to research Maroney and Chai [13] and Makris and Zhang [14], approximately 0.5-0.33 are assumed to be end wall. Resistant pressure of the embankment of the abutment increases linearly with displacement and most of the resistant pressure of the abutment is obtained according to the relation (3).

$$\mathrm{P_{bw}\ orP_{dia}} = 239\ \mathrm{A_e}\left[\frac{\mathrm{h_{bw}\ orh_{dia}}}{1.7}\right] \tag{3}$$

More resistant to pressure changes (Pbw or Pdia) based on the ultimate static force has been used in research [13]. In the models of this research, a height coefficient of 7.1 meters has been used based on research Maroney and Chai (1994) [13].

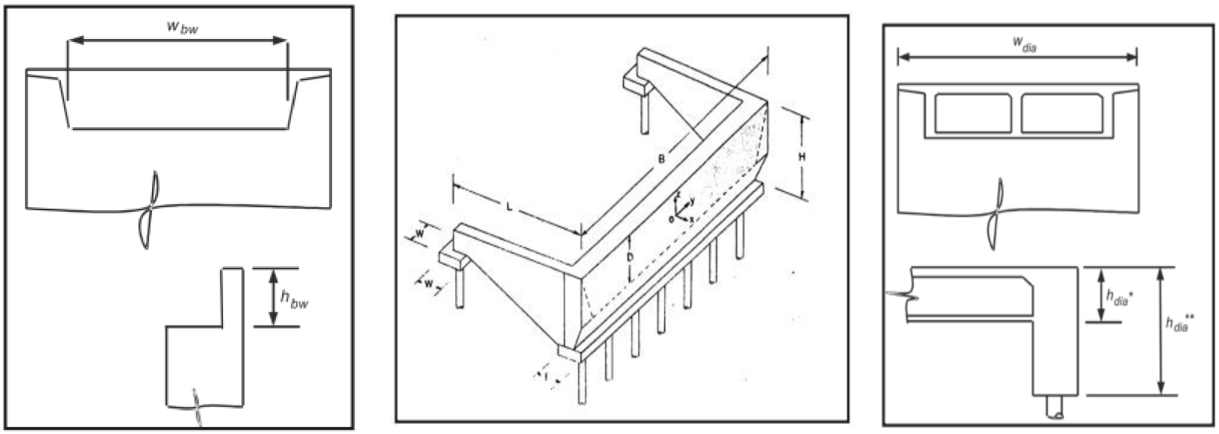


Fig. 4. (a) The specifications and dimensions of the abutment [15], (B and C) How to connect the abutment to the deck [11].

(A) The components of the abutment (middle). (B) A continuous abutment with a deck (right). (C) Non-continuous abutment with deck (left).

Fig. 5. Abutment force -displacement changes with expansion joint and continuous abutment with deck [11].

In order to model the behavior of the abutment, nonlinear bonding elements have been used to model the behavior of the abutment in the longitudinal and transverse directions. In addition, in the longitudinal direction, the gap bonding element has been used for 5 cm expansion joint between the deck and the abutment with the freedom to move in the longitudinal direction. The specifications used for the nonlinear model of abutments in longitudinal and transverse directions are presented in table (2) to table (4).

4.1. Application of different models of abutments

Three roller models, simple and complete, were used to investigate the effect of the abutments on the behavior of bridges. In the roller modeling of the abutment, the roller bolt was used as an alternative to the modeling of the bearings between the abutments and the girders. Because of the simplifying assumptions, the abutment roller model is of great interest to designers and consulting engineers.

Table 2
Characteristics used to model abutments in longitudinal and horizontal directions.

The initial difficulty of the abutments Ki (kN/mm/m)	Maximum Resistant Pressure of embankment Pmax (kPa)	Height factor (m)	Wall influence modulus (C_L)	Wall contribution modulus (C_W)
$11.5*10^2$	239	1.7	0.67	1.33

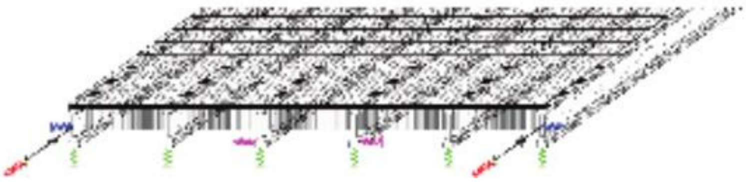


Fig. 6. Complete abutment model.

4.2. Modeling plastic hinges

Hinges nonlinear behavior can be defined by assigning discrete plastic hinge models to possible areas for non-elastic behaviors. In order to convert nonlinear curvature to plastic rotation, an approximate length must be defined for the plastic hinge. There are various methods for modeling plastic hinges to express nonlinear column behavior. In the present study, two types of plastic hinges, including fiber hinge and the force moment interactive hinge (PMM), have been used to express the ductility of the columns in the lower and upper regions of the abutments and in the length of the plastic hinge. Therefore, in presenting the changes in the ductility and capacity of columns that are subject to severe axial load oscillations, they produce poor results. Therefore, such models are not capable of properly considering the interaction axial force and bending moment and can produce inaccurate results if the column capacity is controlled through the axial load. Therefore, the application of these models to simple and preliminary analysis of two-dimensional bridge models is limited.

5. Seismic evaluation methods of the bridges studied

In order to investigate the seismic behavior of the bridges under study, valid analytical methods should be used in accordance with the rules of the by-laws. These methods of analysis must have the characteristics of the materials, the geometry of the structure and its constituents, the masses and boundary conditions, and the sources of nonlinear behavior of the structural model.

6. Results and Analysis

Three types of roller models, simple and complete abutment models for the bridges studied with the base height and number of different spans, were used to evaluate the impact of different types of abutments models on bridge seismic evaluation. The results include the seismic evaluation of bridges using nonlinear static analysis. Also the application of different plastic hinges in the seismic behavior of bridges is investigated and compared to evaluate the accuracy of application of each type of fiber hinge and interactive PMM by performing nonlinear static analysis of bridges along the longitudinal and transverse directions of the bridge.

7. Dynamic characteristics of bridges in the elastic range

In order to study the effects of abutments modeling on their dynamic characteristics in the elastic range, the rotation time of the first 25 modes of vibration of bridges and also the rotation time of three longitudinal, transverse and complex modes have been studied and compared with changes in bases height and number of spans. Therefore, as in Figure (7), the rotation time of the first 25 vibration modes is provided for bridges with 5 and 6 spans and bases heights of 6 and 8 meters. The results indicate that in the case of double-span bridge, the use of roller abutment model has significantly increased the rotation time of the first vibration mode. In the five-span bridge, almost the same results were obtained for all three abutment models, and in the case of the six-span bridges, the results are almost identical. Due to the greater flexibility of the bases in bridges with a base height of 8 meters, so the bases have longer rotation times than models with a height of 6 meters, but using three models of abutment, they behaved similarly to bridge models with a base height of 6 meters. In the following figure (10), the results related to the rotation time longitudinal, transverse and complex in bridges with base height of 6 and 8 m are presented.

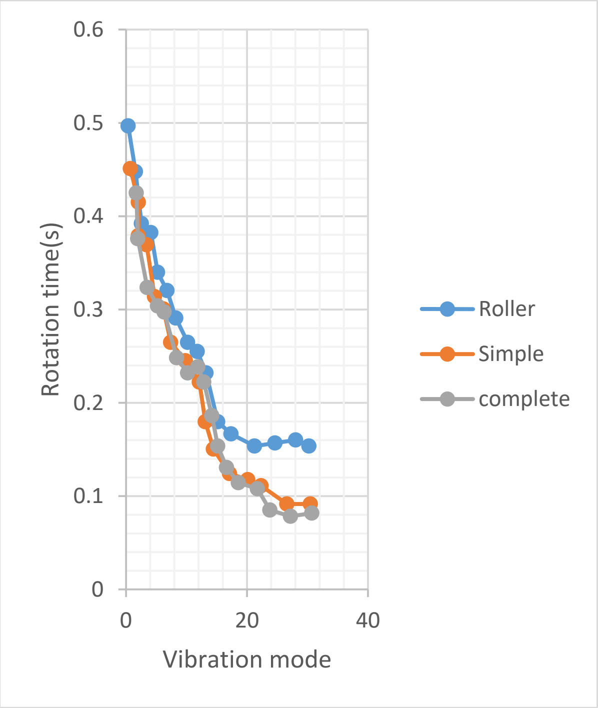


Fig. 7. Six- span bridge with a base height of 6 meters.

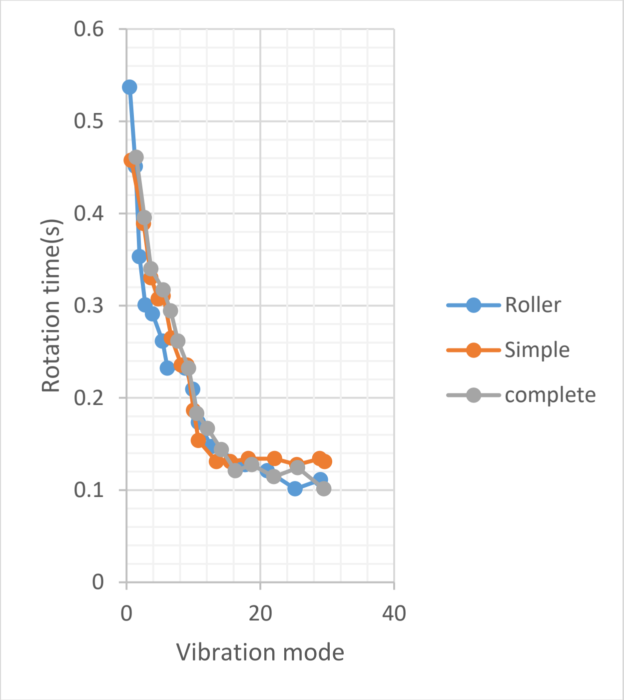


Fig. 8. Five- span bridge with a base height of 6 meters.

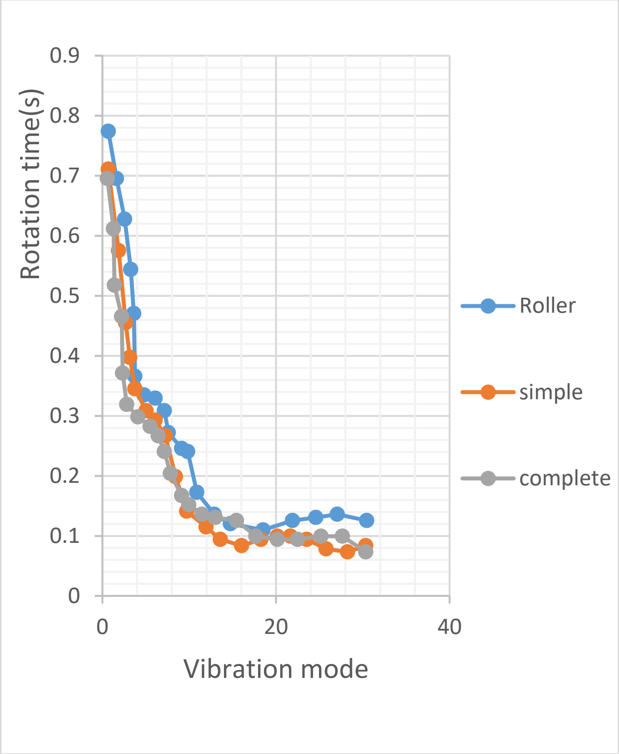


Fig. 9. Six- span bridge with a base height of 8 meters.

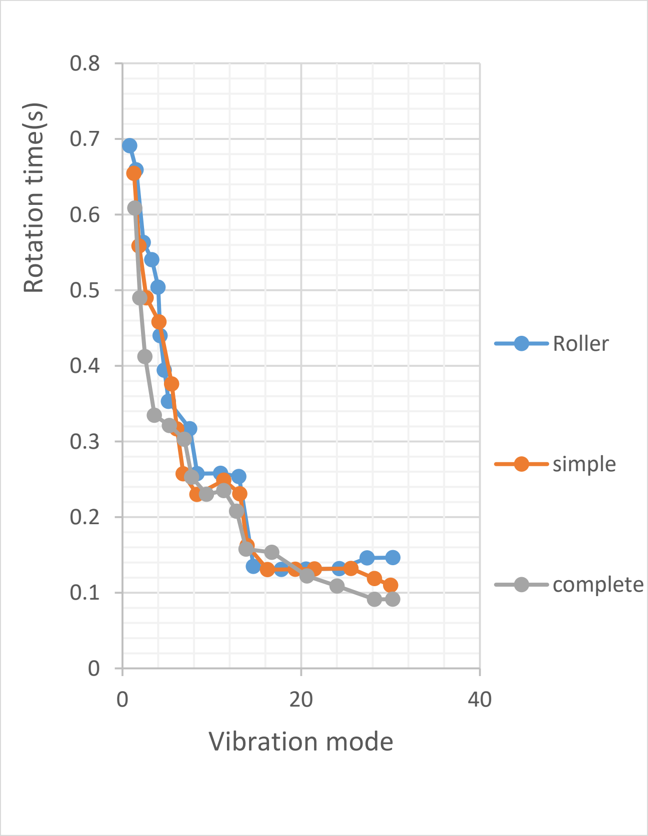


Fig. 10. Five- span bridge with a base height of 8 meters.

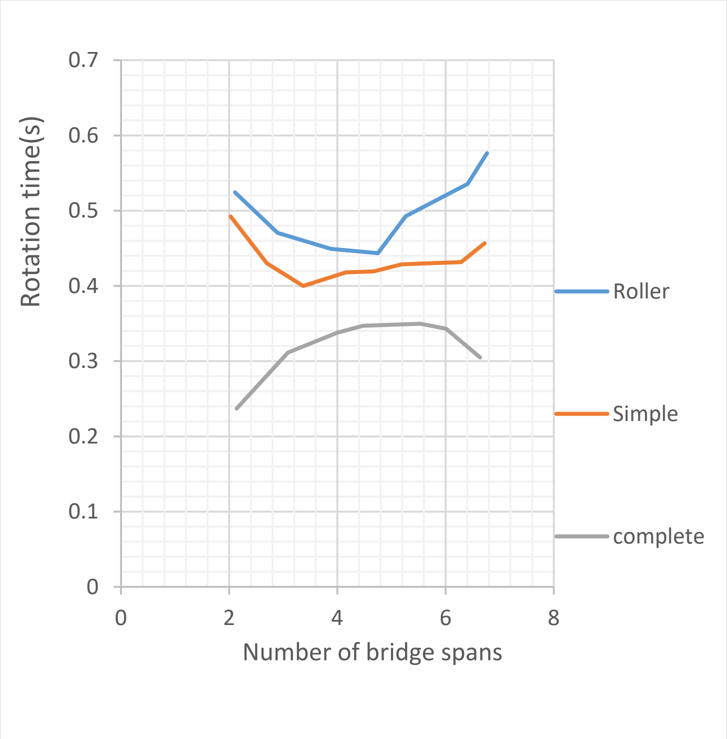


Fig. 11. The fundamental period of transverse vibration in bridges with a base height of 6 m.

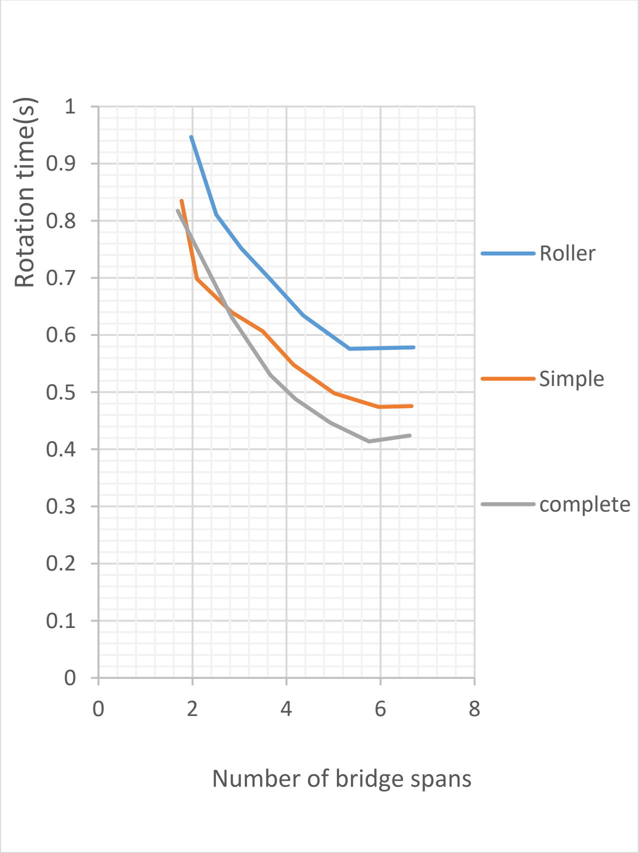


Fig. 12. The fundamental period of longitudinal vibration in bridges with a base height of 6 m.

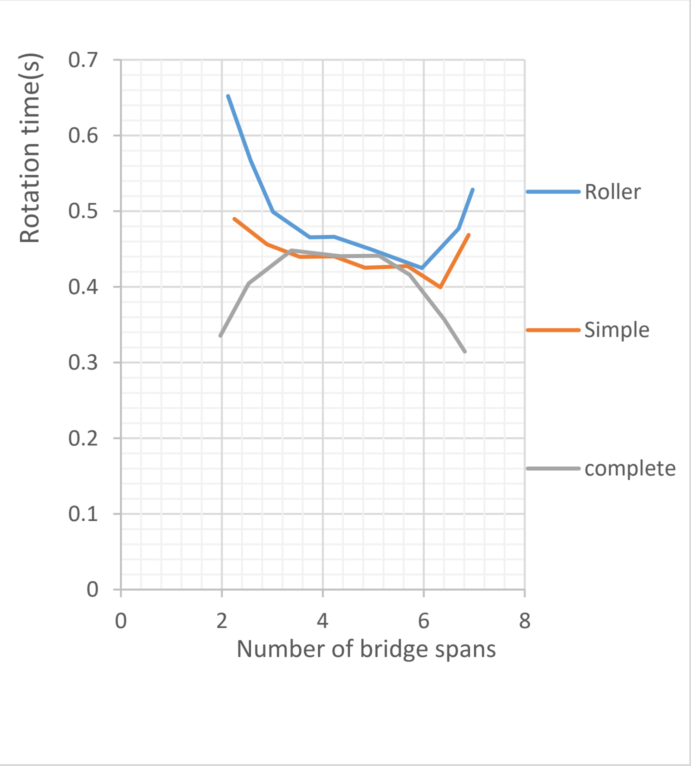


Fig. 13. The fundamental period of transverse vibration in bridges with a base height of 8 m.

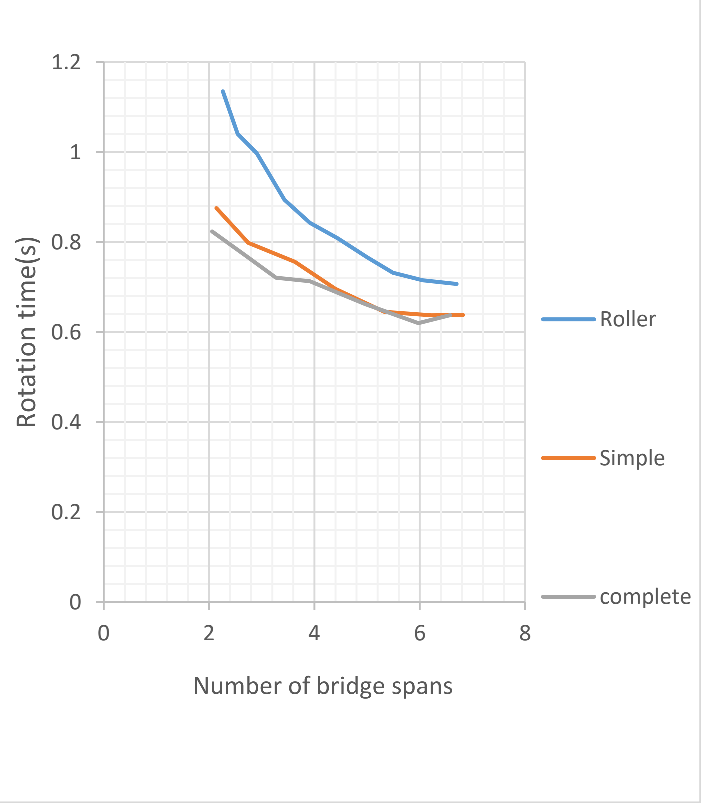


Fig. 14. The fundamental period of longitudinal vibration in bridges with a base height of 8 m.

Based on the obtained results, it can be seen that the longitudinal vibration mode is convergent for bridges with a base height of 6 m using two models by increasing the number of spans and the total length of the bridge, and in the case of bridges six spans (length 95 m) are perfectly matched. The reason for the similar behavior of the two simple and complete models is the presence of expansion joints in the complete model and the non-involvement of the deck with the end wall and the embankment in the range of changing elastic locations. The use of simple and roller models has led to almost the same behavior as bridges in the area of elastic change, and in contrast to the complete model, different behaviors can be observed in the transverse direction. Observing the fundamental period of vibration of bridges with a base height of 8 meters in the longitudinal vibration mode, width with two abutment models, similar results have been obtained with shorter bridges with a base height of 6 meters.

8. Seismic evaluation of bridges using nonlinear static analysis

In order to investigate the effects of how the abutments are modeled on the seismic response of the bridges in the nonlinear displacement range in in longitudinal and transverse both transitional longitudinal and transverse directions, nonlinear static analysis was used. Nonlinear static analysis is generally performed in two methods of displacement control and force control. In this study, the displacement control method with load pattern proportional to the weight of the superstructure (deck) was used in different parts. Therefore it is important to define the forces proportional to the weight of the deck. The displacement of the control is about 1 to 2.5 times the placement debonding limit of the local stud s and is the result of the moment analysis results - footing curvature. In the models studied and based on the calculations performed according to the criteria of nonlinear static analysis, for bridges with a base height of 6 m is equal to 95 cm and for bridges with a height of 6 m 8 m is considered. The control coordinates in all the analysis are considered the midpoint of the deck, which, according to the spans, this point is in all analyzes the location of the deck junction and the middle column head. After analyzing and calculating the base shear variations against the displacement of the control point then the force-displacement diagram is obtained in two longitudinal directions. All three bridges have the same hard to expand expansion as the two simple and complete abutment models, but after the expansion joint is closed, the roller and plain model differ significantly from the full model.

Although the difference in base shear at the two-span bridge is greater, as the length of the bridge increases, the difference between the two simple and roller models is reduced compared to the full model. This appears to be due to an increase in the number of cantilever bases from 5 to 6 spans in the longitudinal direction and a decrease in the influence of the elishes role in the longitudinal direction. For the transverse direction of the bridges, the analysis and calculation of the base shear variations against the displacement of the control point are performed and the force-displacement diagram is presented, as shown in the figure. According to the results obtained in the transverse direction, due to the hardness of the bridge transverse frames and the hardness of the columns, the two simple and roller models have shown similar behavior.

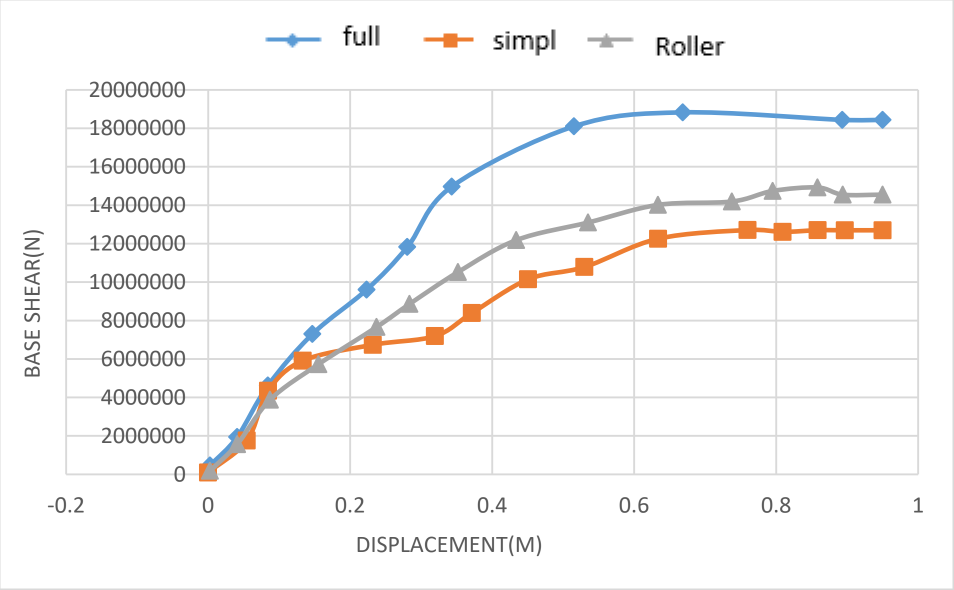


Fig. 15. 5 spans bridge with base height 6 meters in longitudinal direction.

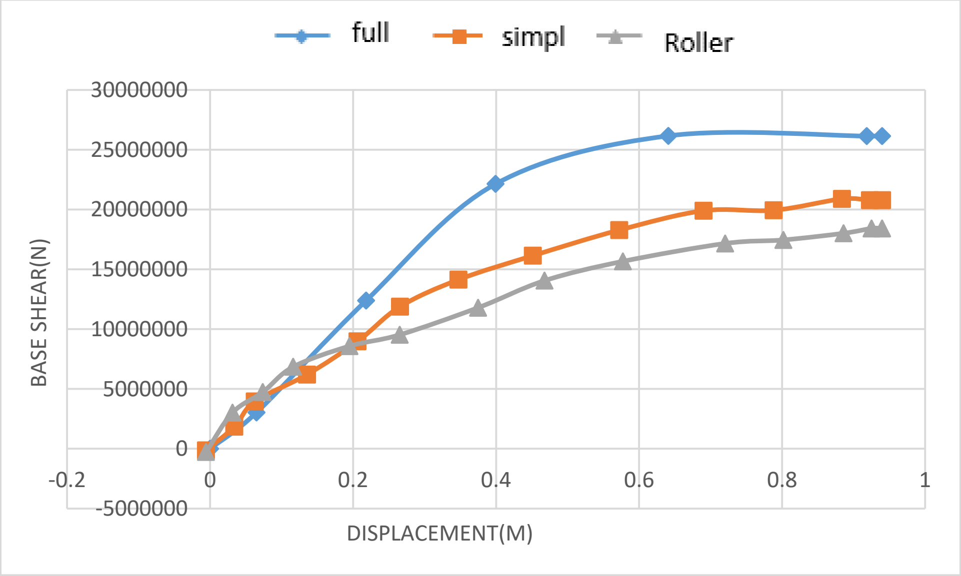


Fig. 16. 6 spans bridge with base height 6 meters in longitudinal direction.

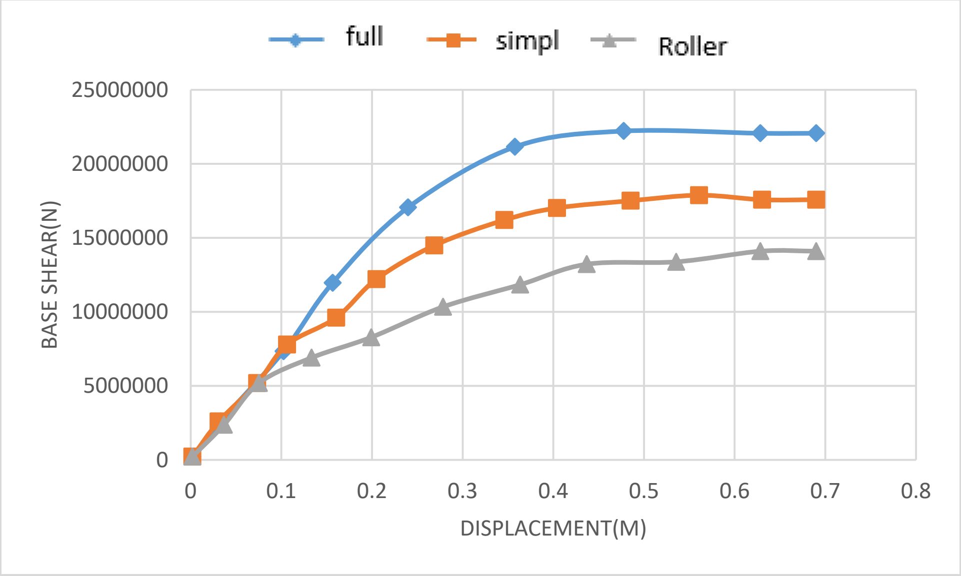


Fig. 17. 5 spans bridge with base height 6 meters in transverse direction.

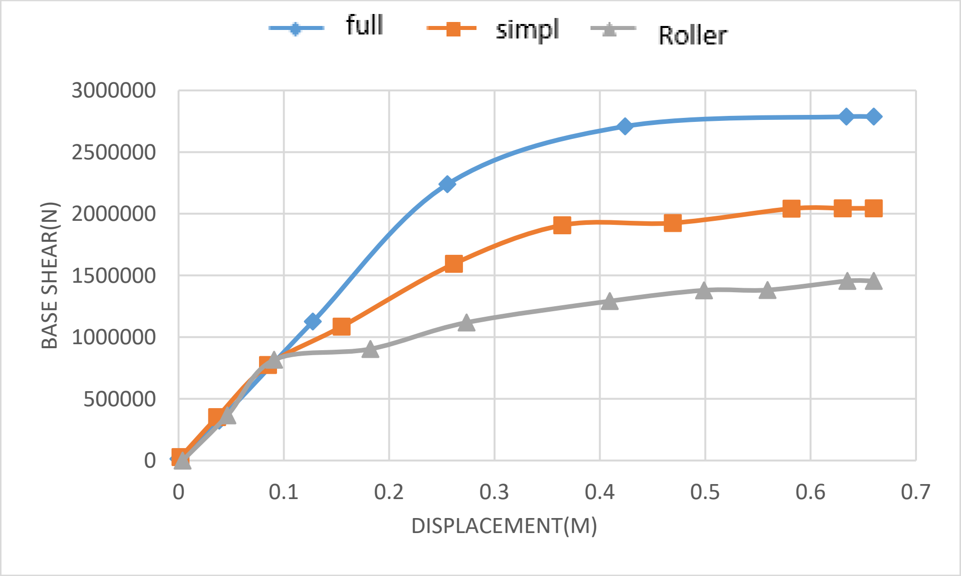


Fig. 18. 6 spans bridge with base height 6 meters in transverse direction.

Both simple and roller models estimate less lateral hardness than the full model due to the ignition hardness of the shear connectors, Fine grained soil and wing walls. Fig. 18 shows the maximum difference of the base shear in the transverse direction for the two simple and roller models compared to the full model with increasing number of spans.

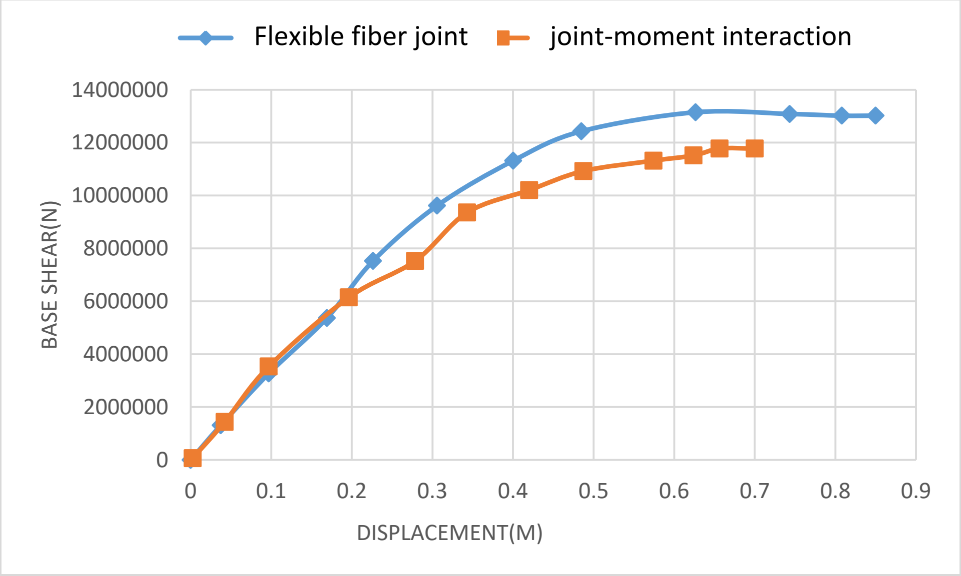


Fig. 19. Longitudinal direction of the bridge.

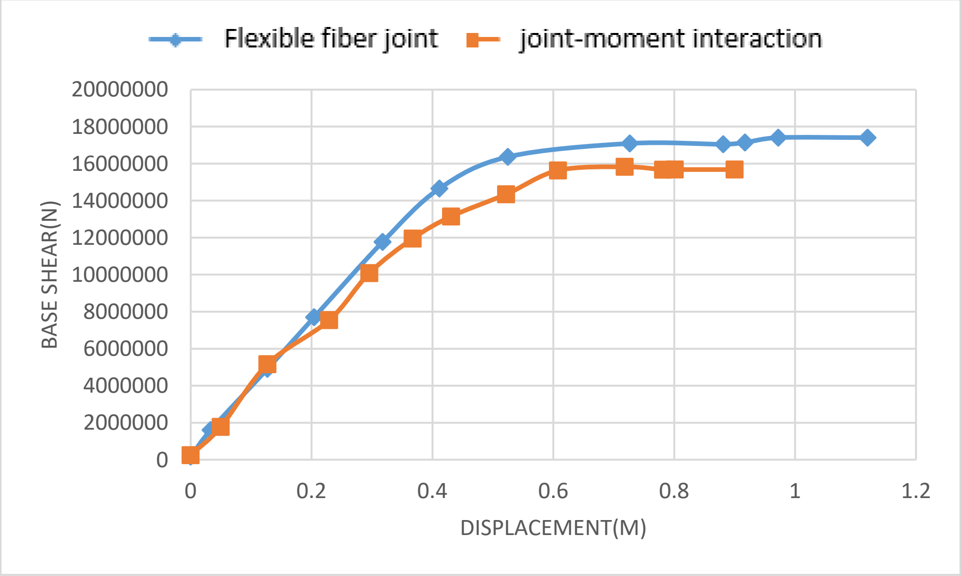


Fig. 20. Longitudinal direction of the bridge.

After modeling the abutments using the introduced hinges and performing a nonlinear static analysis of the abutments' behavior has been studied. Given the similar behavior of the types of bridges, therefore, the results for a sample of bridges in the longitudinal and transverse directions of the bridge are presented in Figures 19 and 20. The results show that modeling of the nonlinear behavior of the abutments using different hinges in the longitudinal and transverse directions of the bridge yielded approximately the same results. This behavior has been repeated similarly to other bridges and analysis along their major axes. The only difference was the magnitude size of the base shear and the maximum displacement. Whereas application of PMM interactive hinges and flexible fiber hinge due to proper distribution of forces and considering different curvature moment diagrams with different axial load levels will lead to better results.

9. Conclusion

Since the bridges studied are existing and common bridges in the country, therefore the results will be used for design, modeling and evaluation of seismic bridges with simple span and integrated slab. On bridges with simple span and integrated slab, the maximum length is 95 meters. To calculate the capacity of the bridges in the longitudinal direction and considering that the two simple and roller models differ from the full model in the 95-meter ‹so the use of the complete abutment model will lead to more accurate results. In bridges with a length of 95 meters, the impact of the abutment in the longitudinal direction is lessened. In the case of 95 meter bridges, due to the reduction of the difference of the results of nonlinear static analysis between the three models, therefore, the use of a simple or roller model in the transverse direction would yield acceptable results. Thus, to evaluate short bridges in the longitudinal direction, the use of a roller model will result in large amounts of error in the results. In the case of long bridges (at least 95 m) due to the number of intermediate abutment and the reduction of the difference between simple and complete models, a simple model can be used to evaluate the bridge. In the transverse direction, by comparing the two simple and roller models with the full model, the number of spans increases, the effect of the abutment model on the bridge performance decreases, and for the 95-meter bridge with the three abutment models, the responses are similar. Therefore, using a full model will be more accurate to evaluate medium-sized bridges structure (40 to 80 meters in length). Roller models can be used for long bridges (at least 95 meters). As the number of spans increases, the effect of the abutment model on bridge performance is reduced, and for the 95-m bridge the responses are similar to the three abutment models. Therefore, using a full model will be more accurate results to evaluate medium-sized bridges structure (40 to 80 meters in length). For long bridges (at least 95 meters) a roller model can be used to evaluate the performance of the bridges in the transverse direction. Application of plastic hinge in modeling and analysis given that the flexible fiber hinge model, such as the ideal PMM interactive hinge under oscillating axial load conditions, has the ability to more accurately evaluate the behavior of column under curvature applied and axial strain for transverse section. Consequently, its application to three-dimensional static and dynamic analysis is suggested. Seismic behavior analysis of v-shaped bridges with considering the effects of abutments and plastic hinge were studied under ground motion in both longitudinal and transverse directions of the bridges. The novel isolation bearings are effective in minimizing the displacement demand on the bridge deck and the force demand on the bridge piers, according to numerical results from nonlinear time history analysis. The isolated bridge's normalized base shear in each pier is roughly three times lower than the conventional bridge's. The piers are subjected to a strong earthquake force, which causes flexural yielding in the weak direction of the conventional bridge's piers. The pier's energy dissipation is greatly reduced because to the fusing abutment. The typical bridge's relative deck movement exceeds the bearing deformation limit, between the deck and the back wall, producing intense pounding the abutment back fill has exceeded its yielding deformation limit as a result of the pounding force.

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